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ELECTRICAL OUTPUT OF M371A1 LUCKY ASSEMBLIES FOR DIFFERENT IMPACT ANGLES

by

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December 1971

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13. ABSTRACT

Laboratory measurements have been made to determine the energy output of piezoelectric "Lucky" elements used in the M371A1 HEAT round under impact at different angles between 0 and 65 deg. Massive steel projectiles are accelerated by a light-gas gun to 700 ft/sec and impacted against fixed fuze spike assemblies (containing the Lucky) with the angle of impact being variable. The energy output from the Lucky into fixed resistor loads (which simulated the T-21 detonator) or actual T-21 detonators is determined from oscillographic records of the instantaneous voltage and current. The energy delivered into a 600-Ω load ranged from a maximum near 90,000 ergs for a 10-deg impact to only 380 ergs for a 65-deg impact. The standoff distance varied between 7.3 in. for 0 deg and 8.3 in. for 65-deg impacts.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Lucky element	8	3				
M371A1 HEAT round	8	3				
Piezoelectric element	8	3				
Detonator	8	3				
Lucky element energy output	8	3				
Standoff distance	8	3				

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ABSTRACT

Laboratory measurements have been made to determine the energy output of piezoelectric "Lucky" elements used in the M371A1 HEAT round under impact at different angles between 0 and 65 deg. Massive steel projectiles are accelerated by a light-gas gun to 700 ft/sec and impacted against fixed fuze spike assemblies (containing the Lucky) with the angle of impact being variable. The energy output from the Lucky into fixed resistor loads (which simulated the T-21 detonator) or actual T-21 detonators is determined from oscillographic records of the instantaneous voltage and current. The energy delivered into a 600-Ω load ranged from a maximum near 90,000 ergs for a 10-deg impact to only 380 ergs for a 65-deg impact. The standoff distance varied between 7.3 in. for 0 deg and 8.3 in. for 65-deg impacts.

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ACKNOWLEDGMENTS

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1.   INTRODUCTION

Tests conducted by Picatinny Arsenal in 1970 on the 90-mm
M371A1 HEAT cartridge showed an unacceptably high rate of mal-
functions for high impacting angles, particularly those ap-
proaching 65 deg. The suspected reason for malfunctions was
insufficient energy output from the Lucky elements at high
impact angles. A series of laboratory measurements was under-
taken by the Harry Diamond Laboratories to test this theory.

In these tests, the energy output of sample Luckies mounted
in their spike assemblies was determined for impact angles of 0,
10, 20, 30, 45, and 65 deg at an impacting velocity of 700 ± 30
ft/sec. Oscillograms of the instantaneous voltage were obtained
for Luckies working into a fixed 600-Ω load, or voltage and cur-
rent for Luckies connected to actual T-21 detonators. From these
records, the energy delivered was computed. A measure of the
standoff distance was also obtained. Six Lucky elements (three
tested at a time) were evaluated at each of the six angles with
a 600-Ω load, and twelve were tested (also three at a time) with
the T-21 detonators at 65 deg only.

In field use, the projectile traveling at high velocity
strikes an essentially fixed target, compressing the Lucky
element in the projectile's leading end. The current, produced
instantaneously by the compression, detonates the round.

To avoid telemetering problems in these tests, the situation
was reversed; that is, the Lucky in its spike assembly was sta-
tionary, with a massive 14-lb projectile impacting against it.
The projectile has the desired impact angle formed into its nose
(fig. 1 and 2) and is driven at the desired velocity by the gas
gun. The currents generated by the Lucky are cabled directly
to the recording equipment.

A cross-sectional view of the M371A1 projectile is diagramed
in figure 3. For the jet from the shaped charge to be properly
focused for maximum target penetration, it is necessary that the
explosive be detonated some distance before it contacts the
target; thus, the Lucky is mounted in the tip of a slim "spike"
projecting in front of the charge. The current output from the
Lucky begins as soon as a shock wave from target impact affects
the Lucky. The spike length is such that in the short time
required for the detonator and main charge to ignite and the jet
to form, the projectile will have moved to the optimum position
for penetration. The distance between the shaped charge and
the target at the moment of current output from the Lucky is
called the standoff distance. An exploded view of the Lucky
and spike assembly is shown in figure 4.

The report is concerned primarily with the laboratory
measurements made by HDL to determine if low output from the
Lucky elements caused the high rate of malfunctions at high-
impact angles.

2. EXPERIMENT

2.1 Equipment

The 100-ft long, 4-in. bore helium gun (diagramed in fig. 5) is the central apparatus used for these experiments. The projectile is held in place by an aluminum rod that has a carefully machined groove designed to break at the pressure required to obtain the desired velocity (about 750 psi for these experiments). To fire the gun, the pressure is increased until the rod breaks; the projectile then travels down the evacuated gun tube and past the optical velocity measuring system, finally impacting the target. A massive steel "catch box" (not shown) contains the projectile and wreckage after the shot is over.

Figures 1 and 6 detail the spike assemblies, supporting "can," and pinducer, which is a precision, commercially available, piezoelectric shock transducer element. A precision jig is used to locate the spikes and pinducer, so that at the moment of impact (fig. 1) the projectile contacts the three Luckies and the pinducer simultaneously. The voltage output from the pinducer triggers the recording oscilloscopes at the exact moment of impact, allowing the standoff time to be read from the oscilloscope records as represented in figure 7.

The circuit diagramed in figure 8 is used for tests conducted with a 600-Ω fixed load. Two attenuators are placed in each line between the Lucky element and the oscilloscope. The first attenuator, mounted about 16 in. from the Lucky, divides the signal by about 20 and provides a load of about 600 Ω to the Lucky and an impedance of about 56 Ω to the line. The second attenuator, located at the recording oscilloscopes, matches the line and divides the signal by about 5. Total attenuation is carefully measured for the whole system after assembly.

Each Lucky output is displayed on four oscilloscope channels. To provide a total picture of the output, both a slow sweep (20 μsec/cm) and a faster sweep (5 μsec/cm) are used; the first sweep covers the entire output duration, and the second sweep gives increased resolution for the first portion of the output. For redundancy, one set of sweeps is triggered by the pinducer output, and a second set by the signal itself.

The circuit shown in figure 9 is used with the shots that employ detonators. A 4.7-Ω resistor in series with the detonator serves as a current shunt; as in the 600-Ω load case, the lines to the oscilloscopes are approximately matched.

A z-input from a pulse generator was used to momentarily brighten the oscilloscope beam spot a few milliseconds before impact; this indicated the exact undeflected beam position regardless of any possible drifting of electronics.

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2.2 Lucky and Detonator Pretesting

All Lucky elements and detonators used in these tests were from normal production lots which, presumably, had been checked for proper operation. To further insure that the experimental results were representative, all Luckies and detonators were inspected again before use. No attempt was made to use only "average" units in these tests; however, it was desired to avoid using any clearly deviant units.

Inspection of the Luckies consisted of measuring their capacitance, dissipation constant (which is essentially the internal resistance of the Lucky), and charge output under a small static load. Of the 55 samples tested, none deviated more than 30 percent from the mean. The variation in capacitance was ±10 percent and averaged about 2150 pF; the variation in dissipation was ±30 percent and averaged 0.005;and the variation in static output was ±30 percent, and averaged 0.34 V into 0.04 μF with a 20-lb force.

A check of all detonators was made with a low-current ohm-meter to detect shorts or excessive resistance. The resistance of all detonators fell in the normal tolerance range, averaging about 4.5 kΩ.

2.3 Data Reduction and Computation

The recording oscilloscopes were calibrated in terms of voltage (or current) and time per centimeter of deflection. This calibration allowed the voltage and time history to be read from the oscillograms with a traveling microscope. These data were punched onto cards, entered into the computer, and processed into the plots of voltage and energy given in section 3.1.

Energy is computed for the fixed resistance load from the equation

$$E = 10^7 \int_0^t v^2/R \ dt$$

For the detonator loads, where R is not a constant, the appropriate equation is

$$E = 10^7 \int_0^t v i \ dt$$

Here, E is the energy in ergs, v is the instantaneous voltage, i is the instantaneous current, and R is the fixed load resistance.

In the data summarized in table I, delay time is defined as the time between the first metal-to-metal impact of projectile and spike and the initial voltage rise, the pinducer delineating the instant of impact between projectile and spike as in figure 7.

Delay distance is the distance the projectile moves during the delay time (delay distance = delay time · velocity).

Standoff distance is that distance between the base of the shape-charge liner and the target, measured along the central axis of the spike, at the moment the voltage output begins. The actual distance varies with the obliquity of the target projectile angle and the delay distance.

$$S.O.D. = spike\ length + R_S(tan\ a) - delay\ distance$$

where the spike length is the distance from the base of the shaped charge to the end of the spike (fig. 3), R_S is the spike radius, and a is the target (impact) angle.

Table I. Data from Lucky Angle Impact Tests Using 600-Ω Simulated Detonator Load

Angle	Energy		Peak Voltage		Delay Time		Standoff Distance*
(deg)	(ergs)		(V)		(µsec)		(in.)
0	25,000		2040		1.0		7.29
	38,000		1650		0.5		7.30
	15,000		840		0.5		7.30
	12,000		850		2.0		7.28
	10,000		400		1.0		7.29
	31,000		1710		2.5		7.28
Mean:	22,000 ·	11,300	1250 ·	640	1.2 ±	0.8	7.29 ± 0.01
10	56,000		1000		9.0		7.34
	39,000		630		7.0		7.35
	53,000		830		9.0		7.34
	88,000		960		7.5		7.35
	83,000		1000		7.0		7.35
	46,000		840		8.0		7.34
Mean:	61,000 ·	20,000	880 ·	140	7.8 ·	0.9	7.34 · 0.01
20	30,000		470		13.0		7.42
	34,000		440		17.5		7.38
	28,000		370		14.0		7.41
	18,000		350		14.0		7.42
	38,000		520		13.5		7.42
	34,000		460		13.5		7.42
Mean:	30,000 ·	7,000	435 ·	64	14.2 ·	1.6	7.42 · 0.03

Table I. Data from Lucky Angle Impact Tests Using
600-∴ Simulated Detonator Load (CONT'D)

Angle	Energy		Peak Voltage	Delay Time		Standoff Distance*
(deg)	(ergs)		(V)	(;.sec)		(in.)
30	11,000		260	16.5		7.53
	23,000		320	18.5		7.51
	11,000		190	17.5		7.52
	15,000		360	15.5		7.54
	19,000		350	15.5		7.54
	13,000		290	19.0		7.51
Mean:	15,000 · 5,000		300 · 60	17.1 · 1.5		7.52 · 0.01
45	2,900		120	32.5		7.66
	2,300		120	**		**
	3,400		150	33.0		7.66
	3,000		160	20.0		7.76
	4,000		160	16.5		7.79
	2,700		130	19.0		7.77
Mean:	3,000 · 600		140 · 20	24.2 · 7.9		7.73 · 0.06
65	1,000		90	35.5		8.35
	720		80	39.5		8.31
	380		80	34.0		8.36
	1,400		90	36.5		8.33
	880		90	34.0		8,35
	420		50	38.0		8.36
Mean:	800 · 400		80 · 15	35.4 · 2.4		8.34 · 0.02

*Spike length assumed to be 7.3 in., based on measurement of
two rounds.

**Delay time not obtained due to malfunction.

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3. RESULTS AND CONCLUSIONS

3.1 Luckies with Fixed-Load Resistance

Figures 10 and 11 show the individual computer plots of voltage and energy output into fixed-load resistance. Table I summarizes these results and gives the standoff distance. Figure 12 plots the energy output range for the six angles.

The maximum output energy occurs at 10 deg and not at 0 deg, because of the shorter duration of the 0-deg pulse. The voltage of the 0-deg pulse is as high or higher than that of other angles; however, the very strong shock created by the collision at 0 deg appears to damage the Lucky and electrode structure before all the energy can be delivered.

3.2 Luckies with Detonator Load

Table II summarizes the energy-output results with detonator load (at 65 deg only). The peak voltages are comparable to those at the same angle with fixed load; the peak current and voltage show that the 600- value was a reasonable approximation for a simulated detonator. Although not shown, the standoff distance is the same as that for the fixed-load case. Note that because the detonator fired, the duration and therefore total energy were cut short by the detonator firing (table II).

3.3 Correlation of Lucky Pretest with Performance

Although a precise analysis could not be performed with the limited results, table III suggests that there is no correlation between the prefiring test results on the Luckies and the actual energy output; Luckies varying by less than 10 percent in static output and capacitance produced output varying by nearly 100 percent under shock conditions. It should be remembered that the shock output includes possible effects of the spike, paper insulator, etc. which are not evaluated by the static tests.

Specifications for the T-21 detonator[1] state that it shall have a function reliability of 99.5 percent (90 percent confidence level) when a 2200-pF capacitor at a 300-V potential is discharged into it, and a reliability of 95 percent at 93 V; the energy released is about 1000 and 100 ergs, respectively. The energy required to fire the T-21 detonators used in our test was 33 ergs or less. Thus, it would seem that the reduced output of 380 to 1400 ergs measured at 65 deg with the resistive load would not seriously degrade the reliability. More than 2500 ergs were generated at other test angles which is considerably higher than the 1000-erg value for the 99.5-percent reliability level.

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[1] Electric Initiator Handbook, Franklin Institute, 1961.

Table II. Energy Output to T-21 Detonator, Applied
Voltage from Lucky Elements Impacted by
65-deg Angle Projectiles*

Energy	Peak Voltage	Peak Current
(ergs)	(V)	(mA)
12.0	60	75
29.0	90	80
32.6	90	110
17.5	100	95
19.9	105	246
19.2	82	80
4.3	62	32
16.8	90	94
Mean: 18.9 ± 8.9	85 ' 16	102 ± 63

*These values represent only the energy required to fire the
detonator, and not the total energy available from the Lucky.
During the first instants of Lucky output, the voltage,
current, and rate of energy delivery are similar to those
with the 600-Ω load. However, the detonator fires in about
1 µsec, cutting off the delivery of energy. The standoff
distance is unchanged from that with the 600-Ω load.

Table III. Highest and Lowest Energy Output at Each Angle and the Capacitance and Static Output of the Corresponding Lucky

Angle	Energy Output (600-Ω load)		Capacitance	Static Output Voltage into 0.04 μF for 20-lb Force
(deg)			(nF)	(V)
0	high:	+72% (above mean)	2.2	0.35
	low:	-50% (below mean)	2.2	0.35
10	high:	+45%	2.2	0.33
	low:	-35%	2.2	0.34
20	high:	+25%	2.2	0.37
	low:	-40%	2.0	0.43
30	high:	+50%	2.2	0.36
	*low:	-25%	2.2, 2.2	0.40, 0.28
45	high:	+35%	2.3	0.33
	low:	-25%	2.0	0.38
65	high:	+75%	1.9	0.32
	low:	-50%	2.2	0.38

*At the 30° angle, two Luckies delivered identical energy outputs (25% below the mean); capacitance and static voltage output are shown for both.

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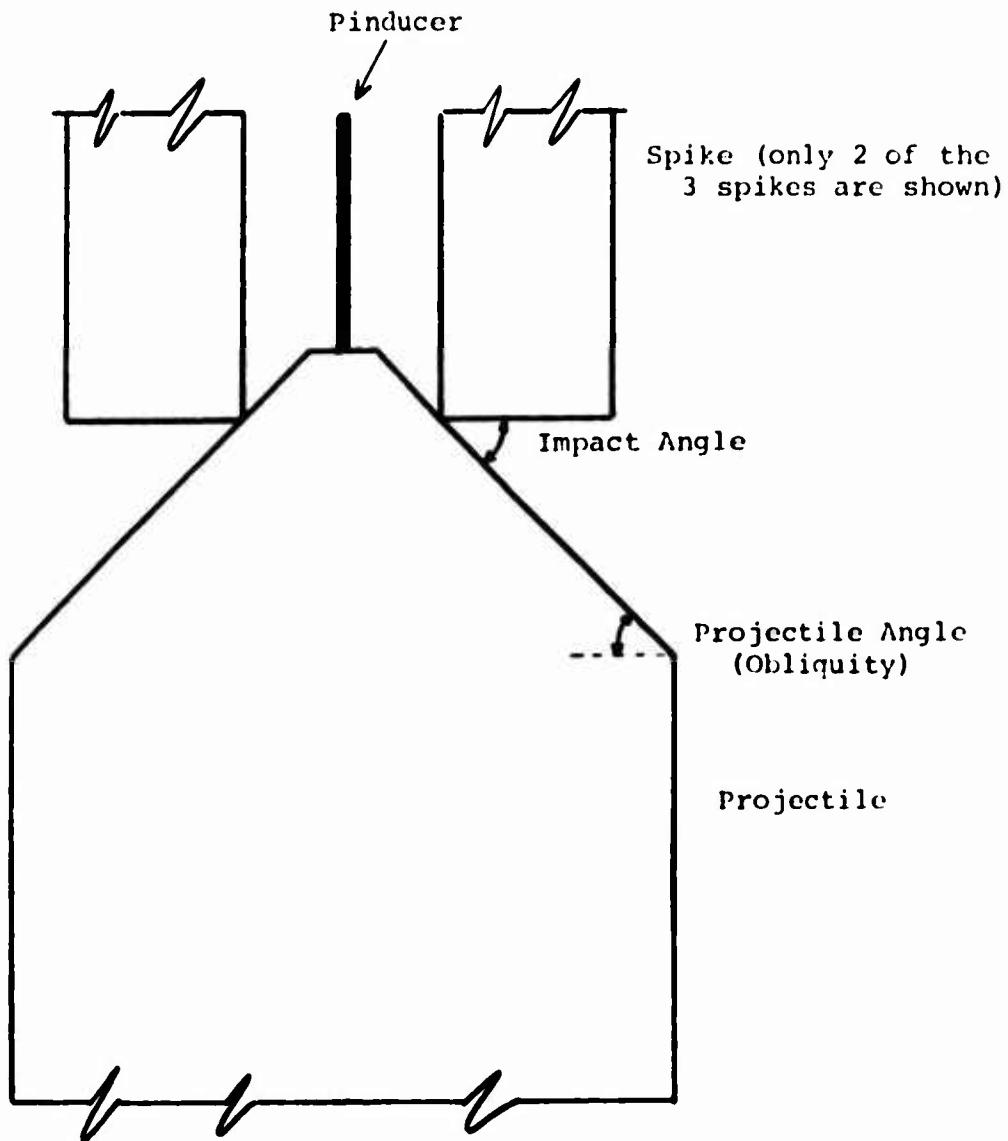
Figure 1. Configuration of projectile, spikes, and pinducer at moment of impact.
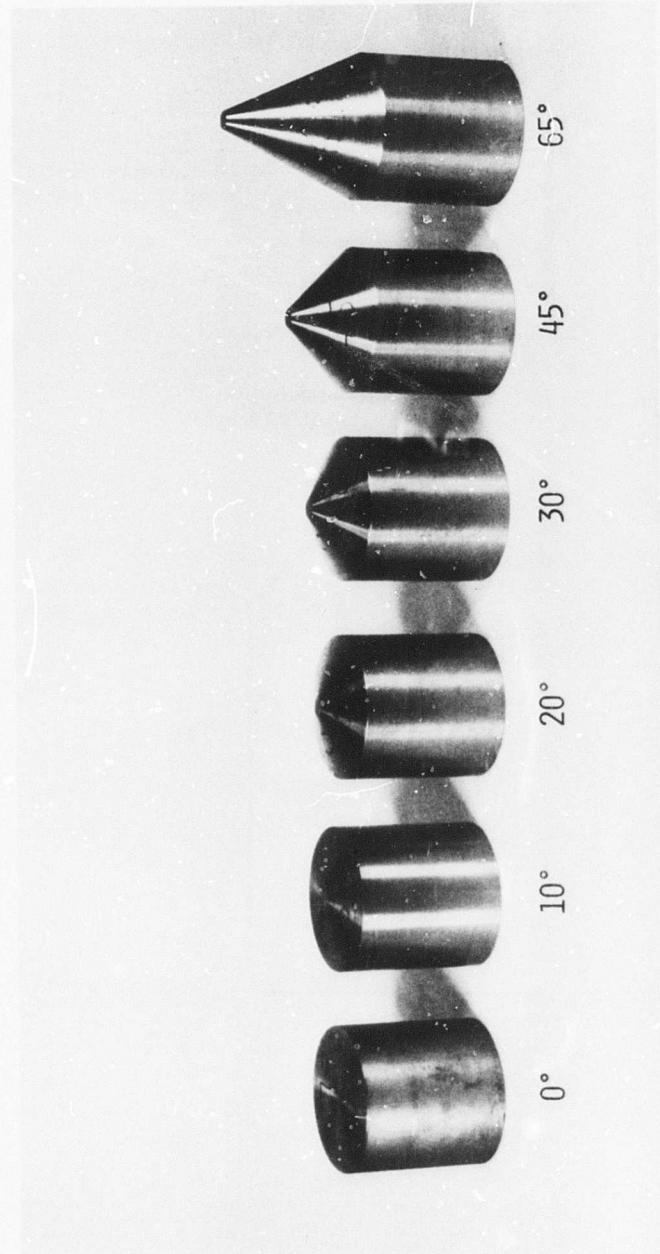
Figure 2. Fourteen-pound steel projectiles with angles as indicated.

SPIKE
ASSEMBLY

LUCKY
ELEMENT

COPPER
LINER

EXPLOSIVE

DETOMATOR
ASSEMBLY
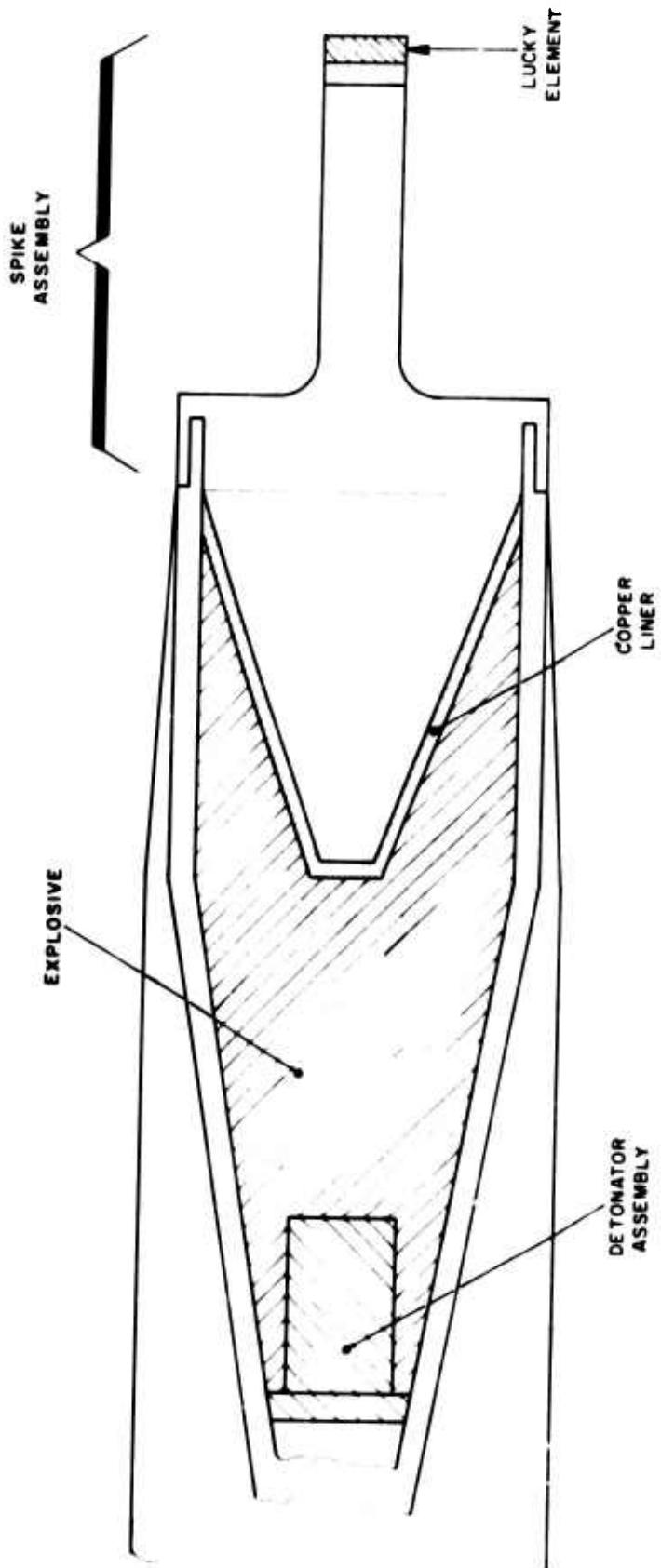
Figure 3. Cross section of M371A1 HEAT round.

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Figure 4. Exploded view of Lucky element assembly in spike
of M371A1 HEAT round: (A) spike; (B) insulator;
(C) Lucky; (D) insulating cap; (E) nose cap.
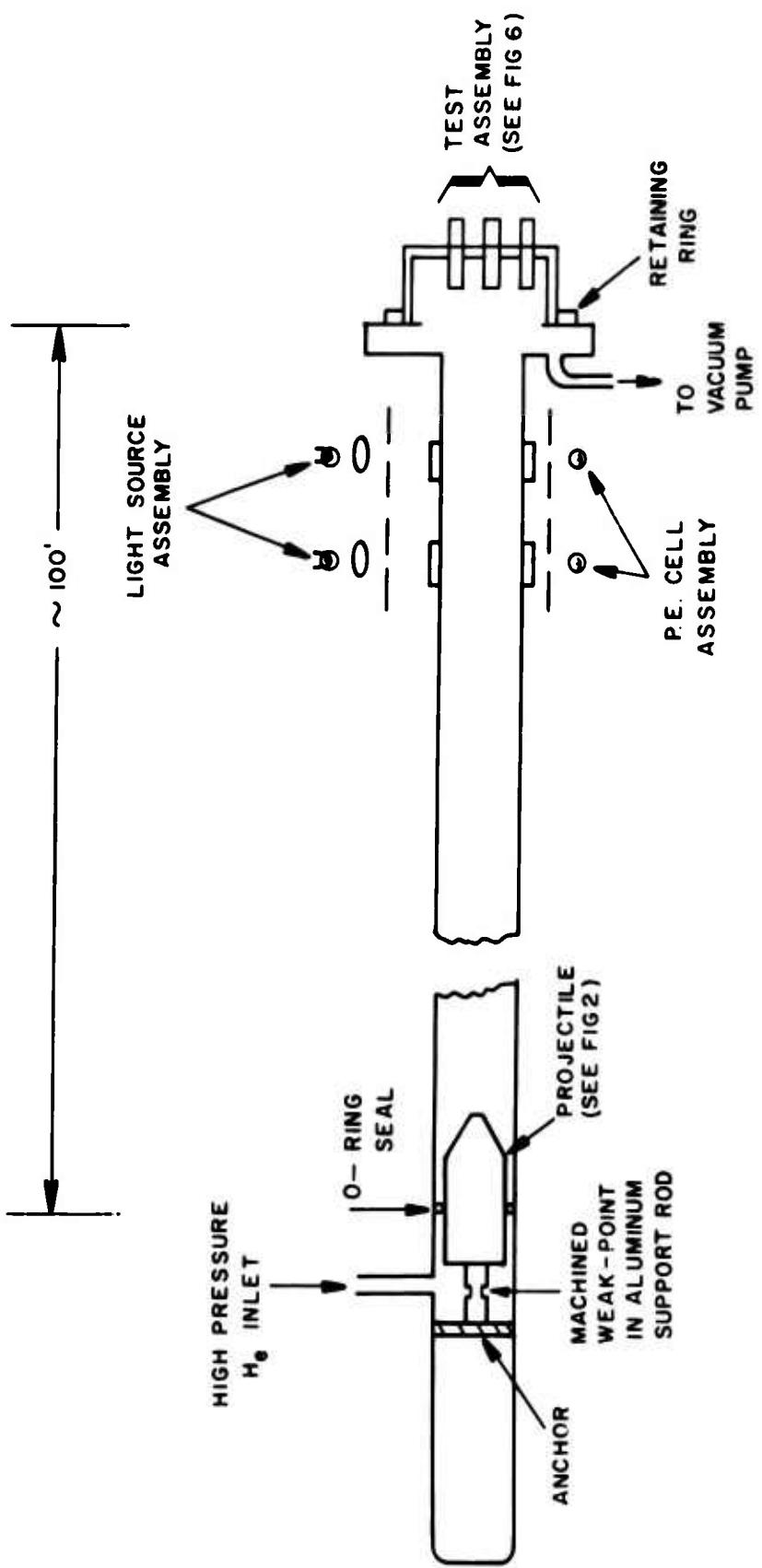
Figure 5. Schematic diagram of Light Gas Gun used in the tests.

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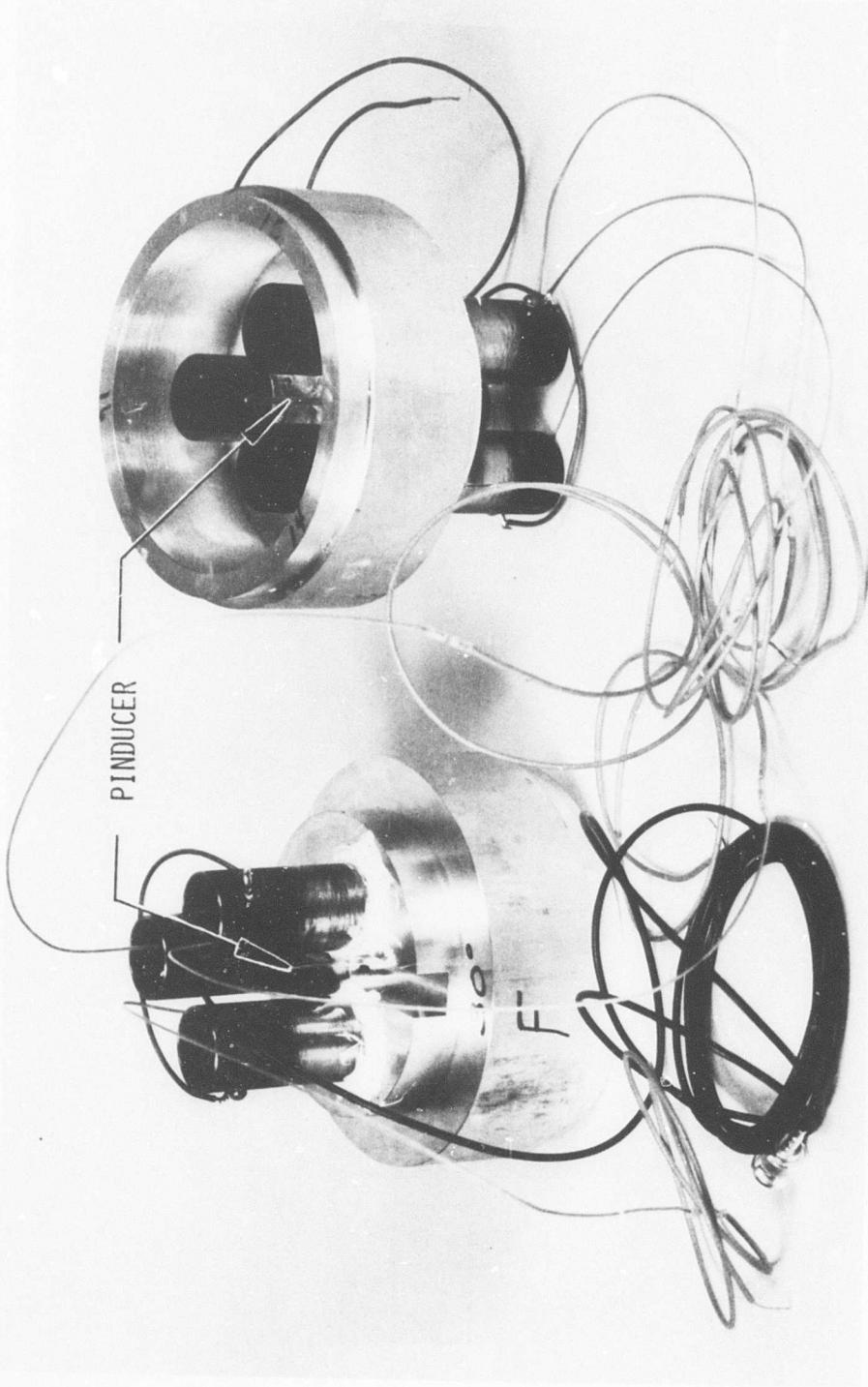
PINDUCER

Figure 6. Fixture ("can") with spikes and pinducer mounted. The flared portion of the spike, shown in figure 4, has been cut off.

20
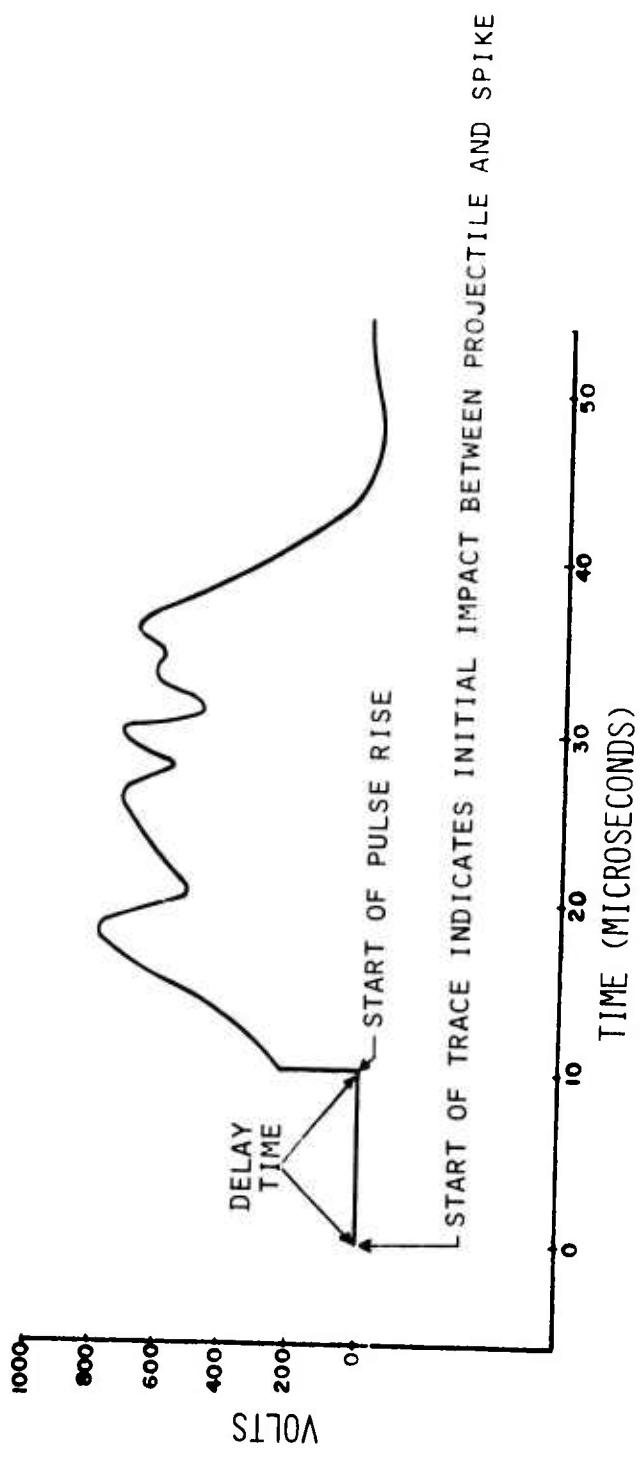
Figure 7. Representation of oscillographic record showing
delay-time.
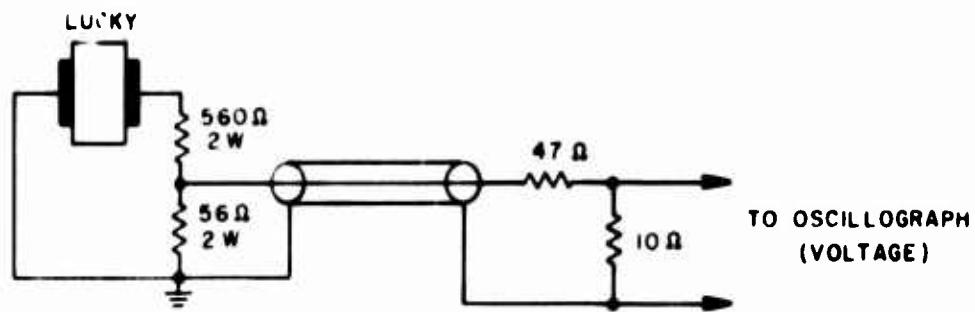
Figure 8. Electrical circuit to measure voltage output of
Lucky element with resistive fixed load.
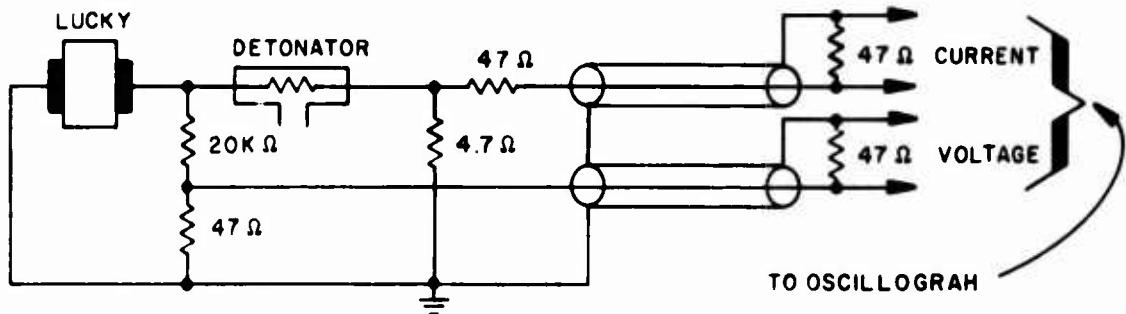
Figure 9. Electrical circuit for measuring both voltage
and current delivered to detonator load.

22
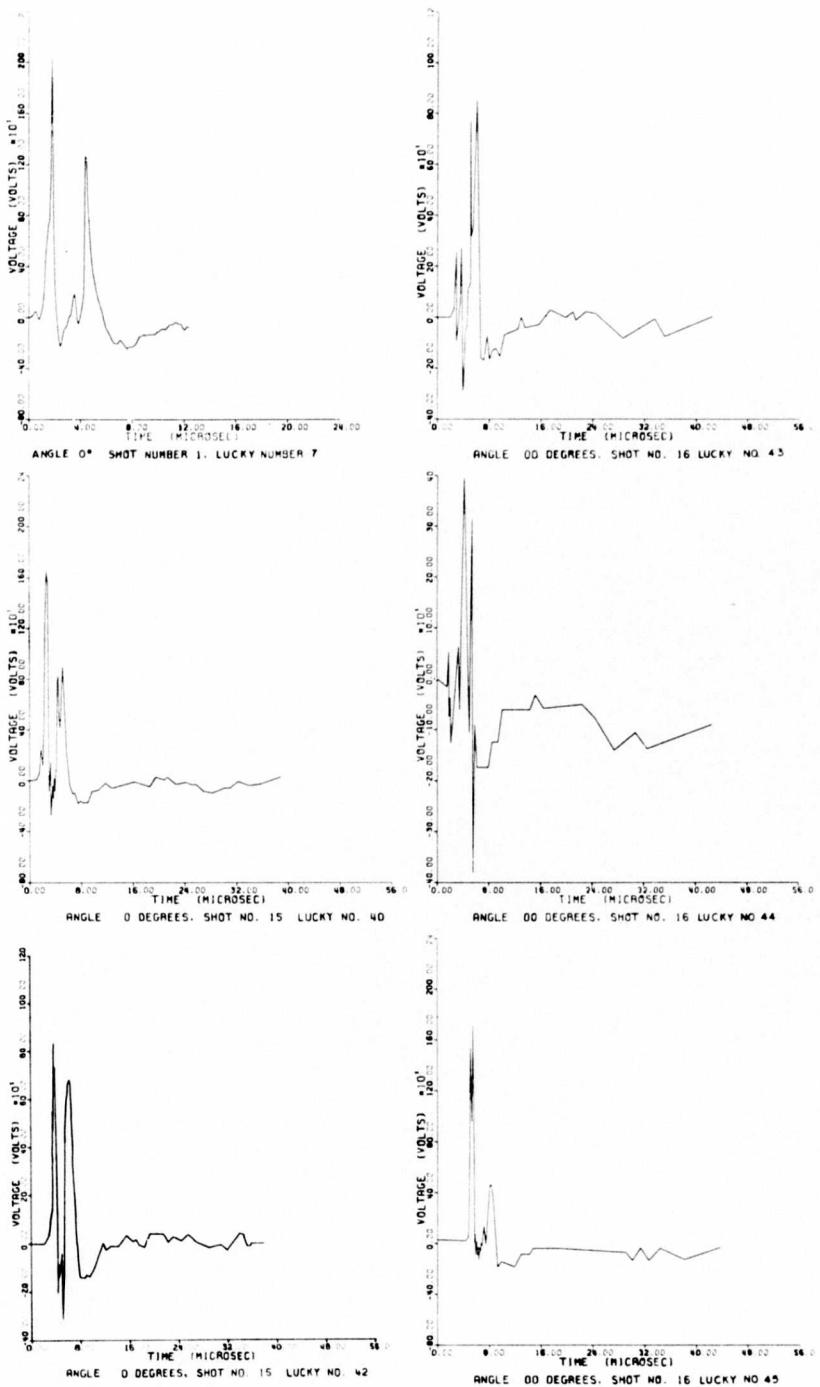
Figure 10a. Computer plots of Lucky output voltage versus time:
Impact angle = 0 deg.

23
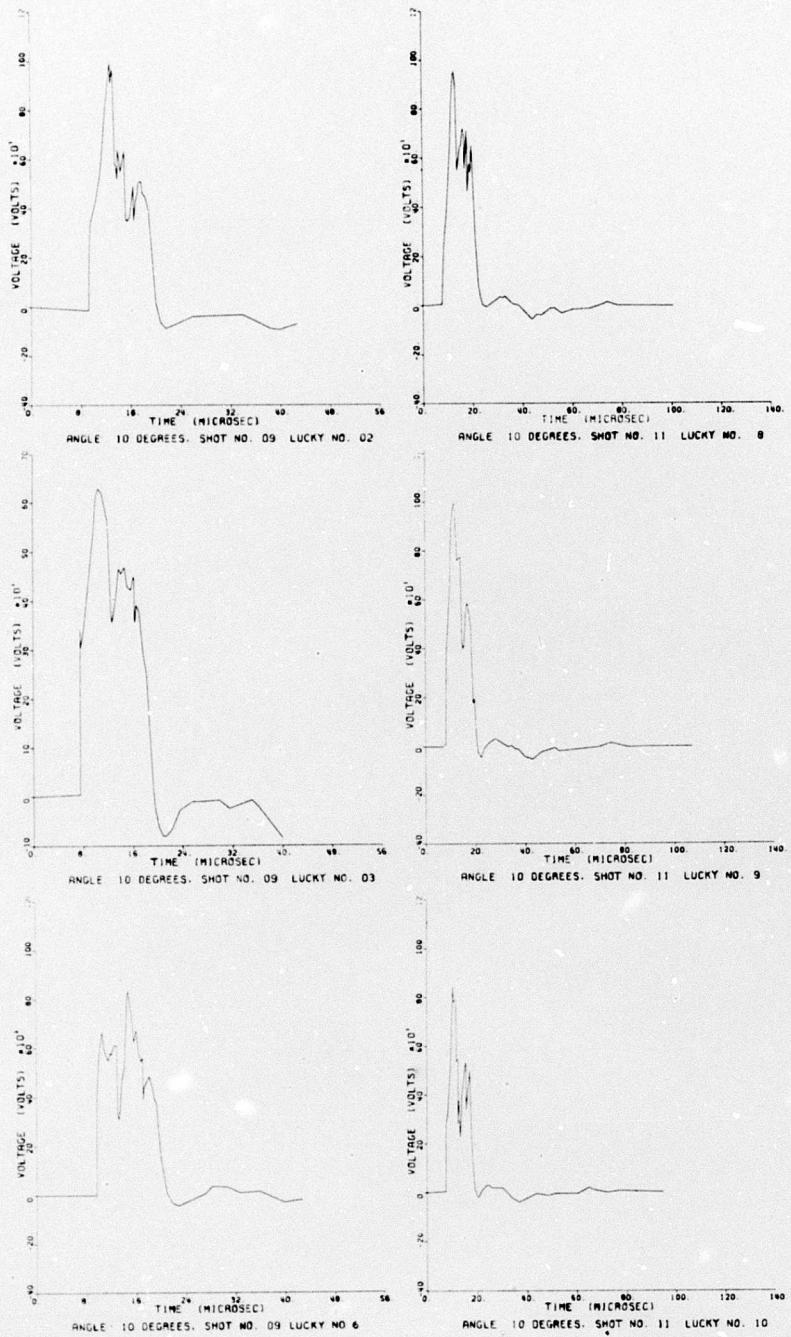
Figure 10b. Computer plots of Lucky output voltage versus time:
Impact angle = 10 deg.

24
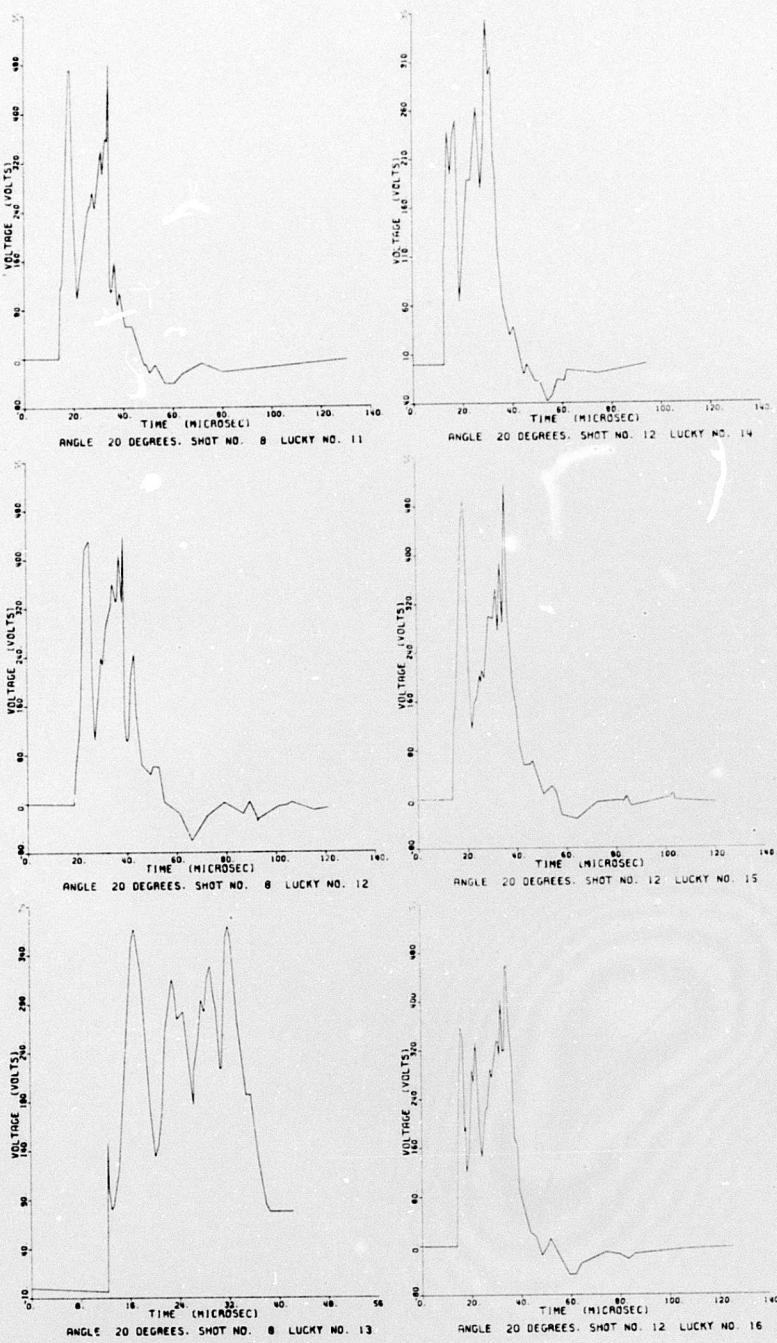
Figure 10c. Computer plots of Lucky output voltage versus time:
Impact angle = 20 deg.

25
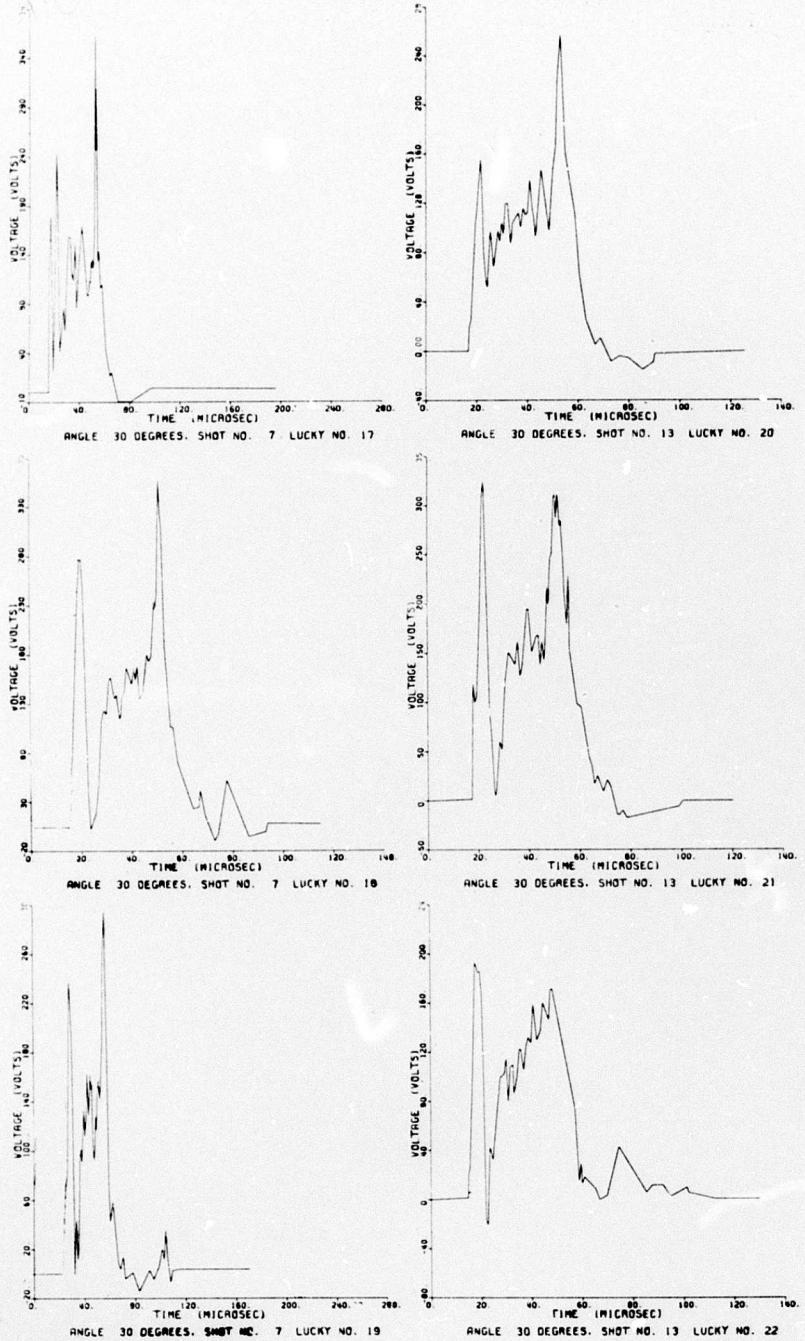
Figure 10d. Computer plots of Lucky output voltage versus time:
Impact angle = 30 deg.

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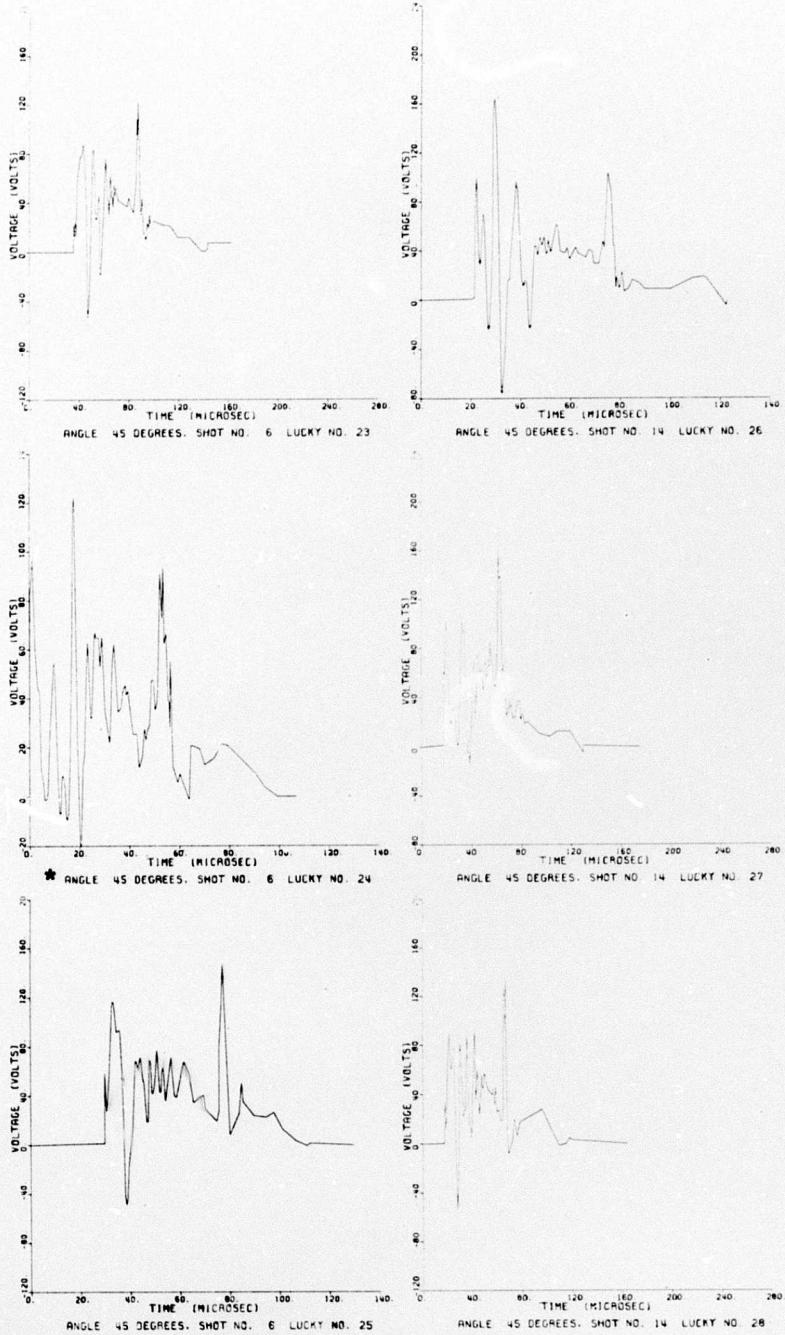
Figure 10e. Computer plots of Lucky output voltage versus time:
            Impact angle = 45 deg.

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*Delay time not obtained; arbitrarily indicated as 0.
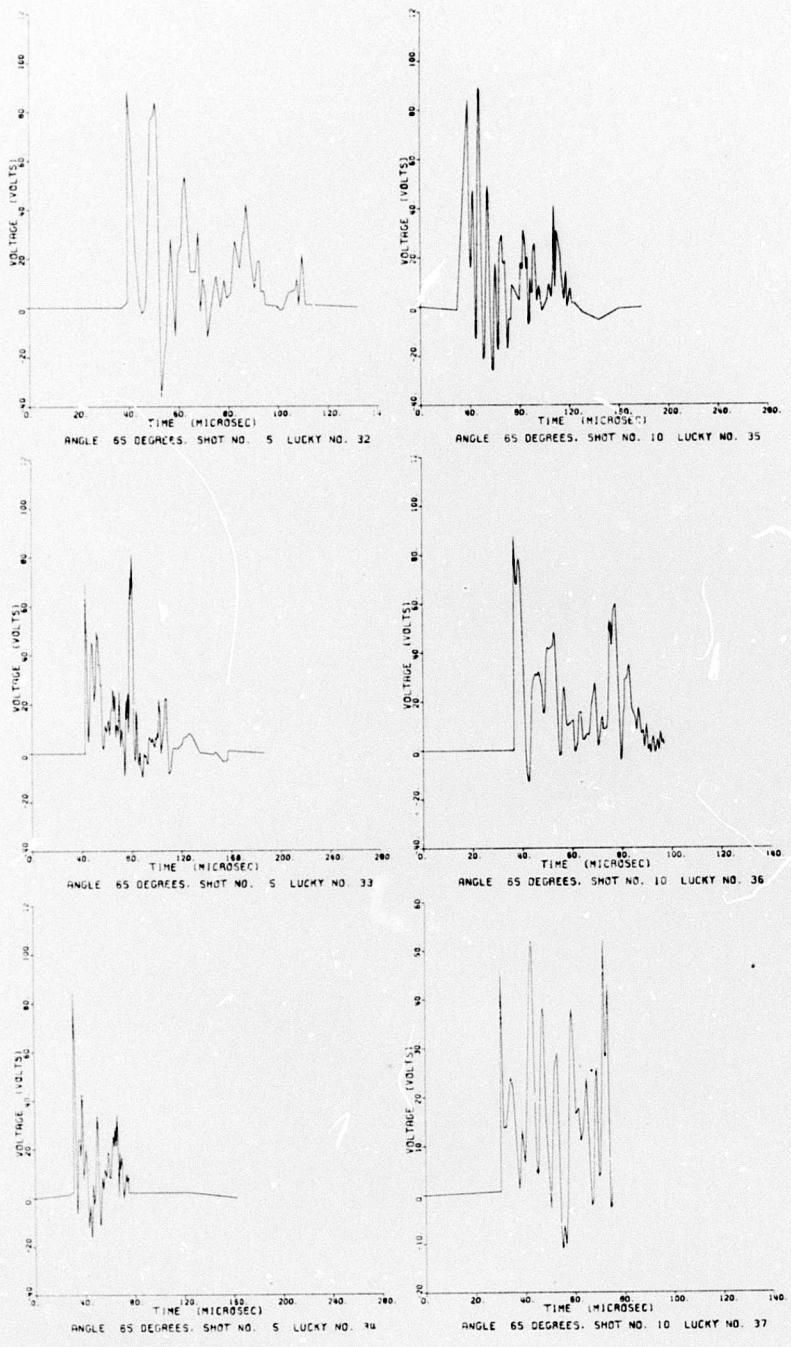
Figure 10f. Computer plots of Lucky output voltage versus time: Impact angle = 65 deg.
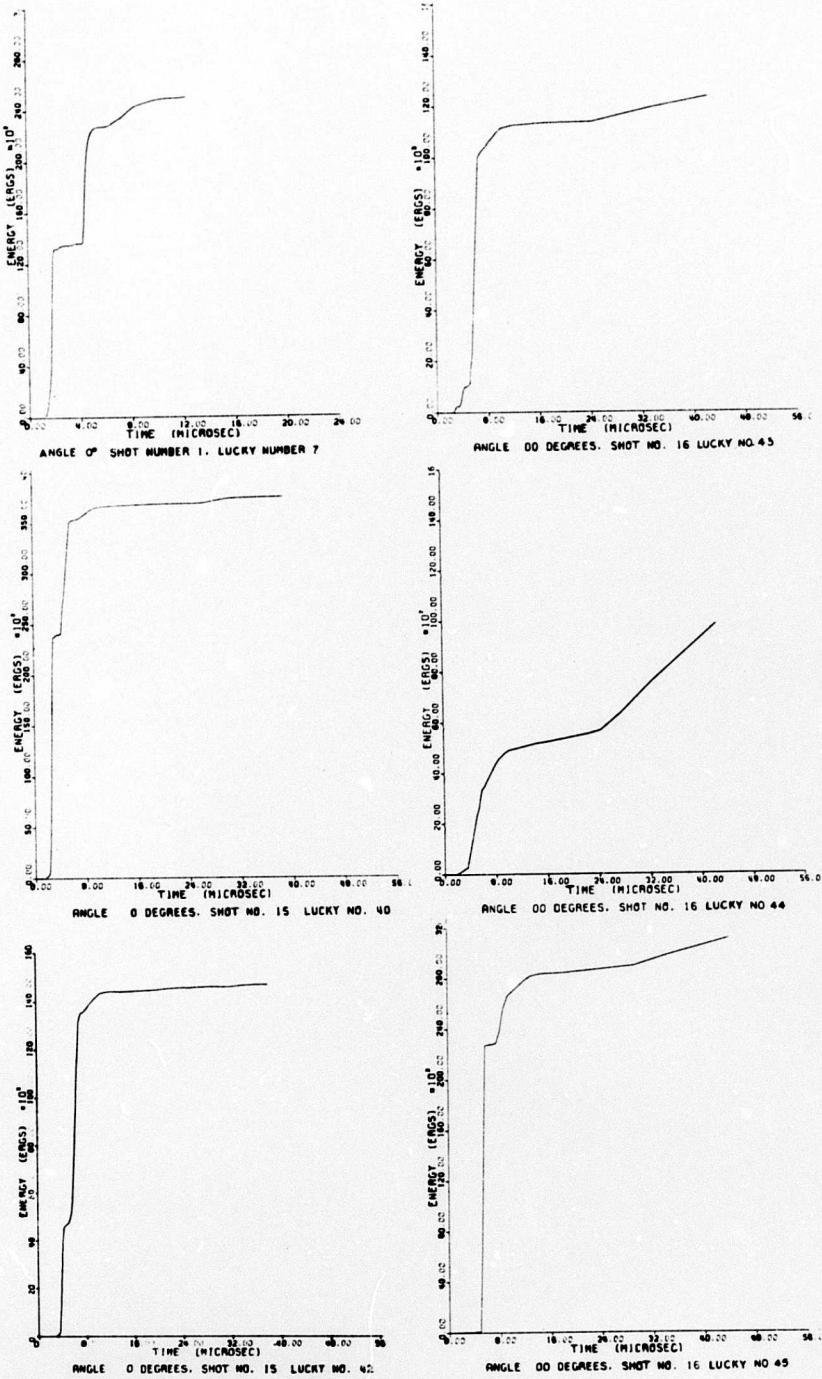
Figure 11a. Computer plots of Lucky output energy versus time:
Impact angle = 0 deg.

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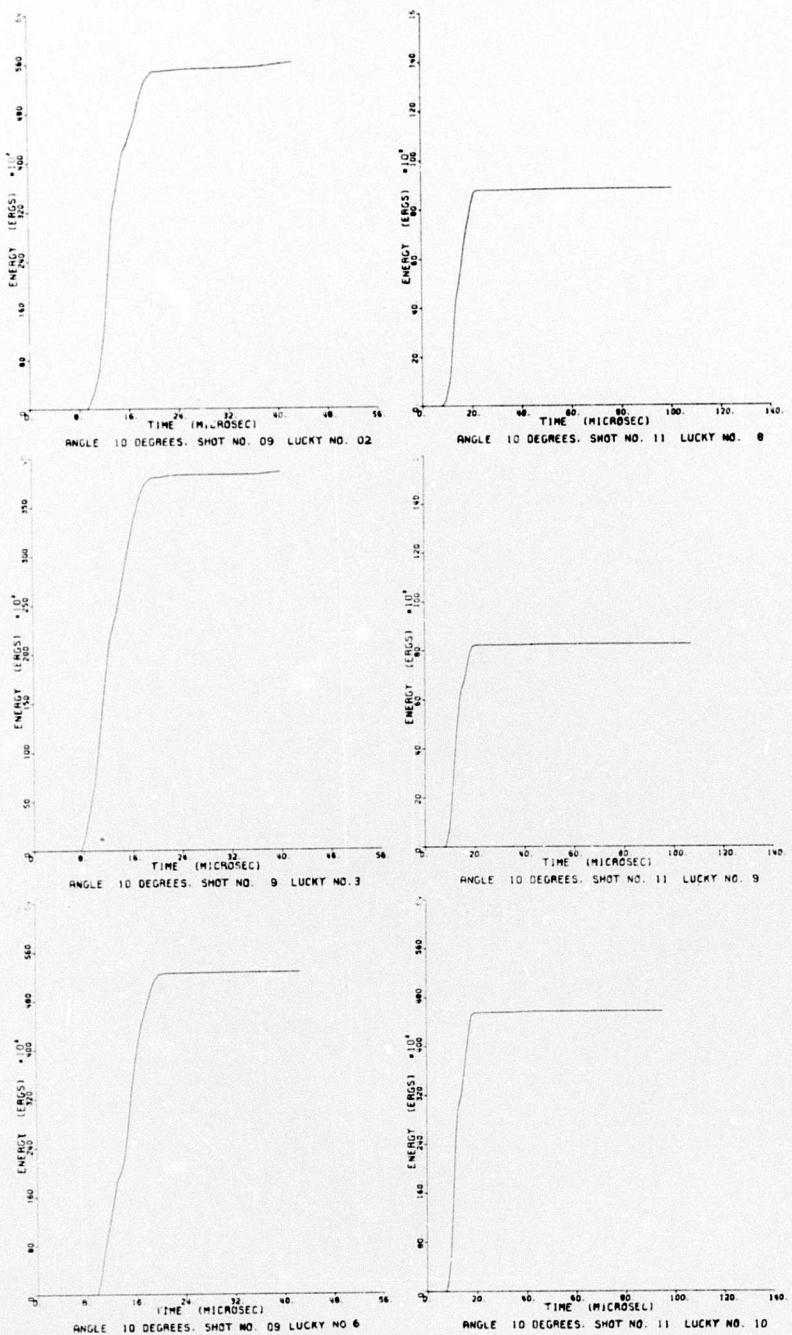
Figure 11b. Computer plots of Lucky output energy versus time:
Impact angle = 10 deg.

30
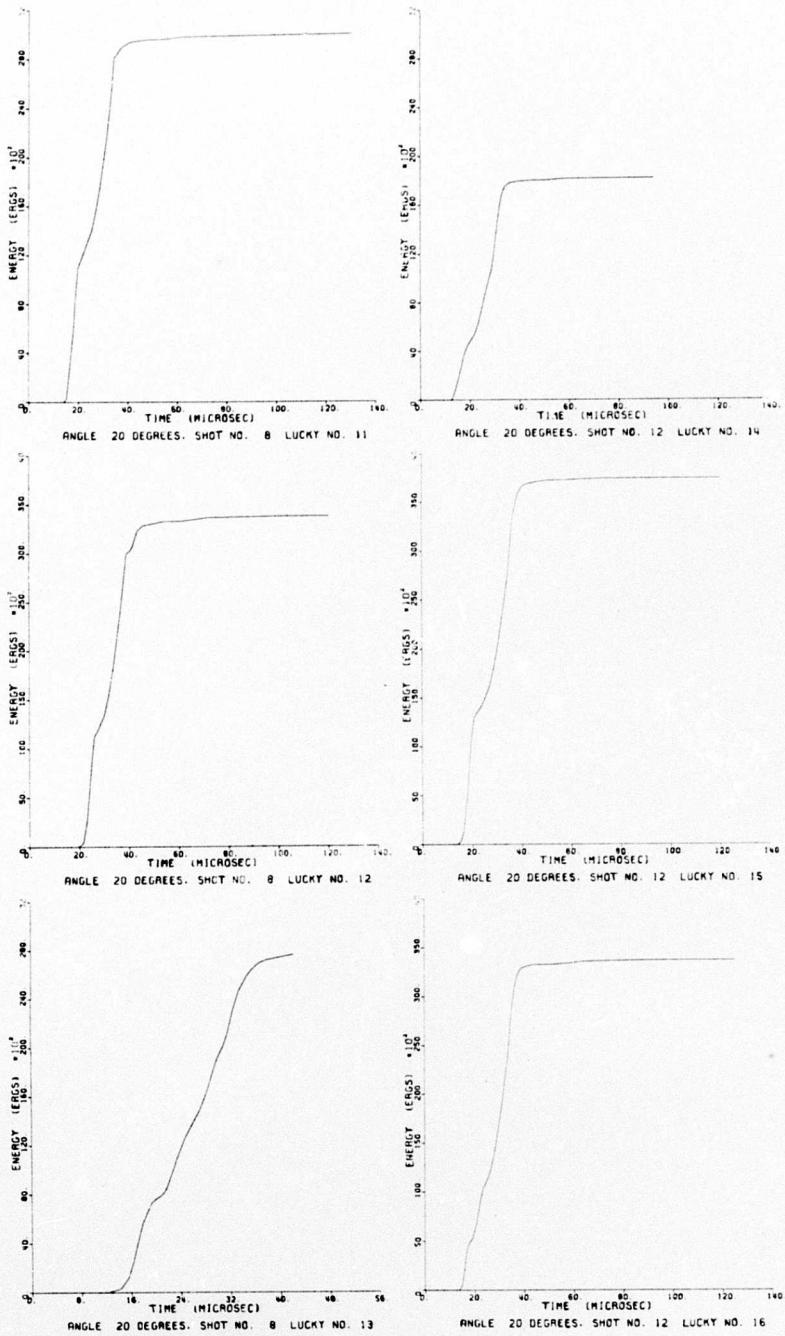
Figure 11c. Computer plots of Lucky output energy versus time:
Impact angle = 20 deg.
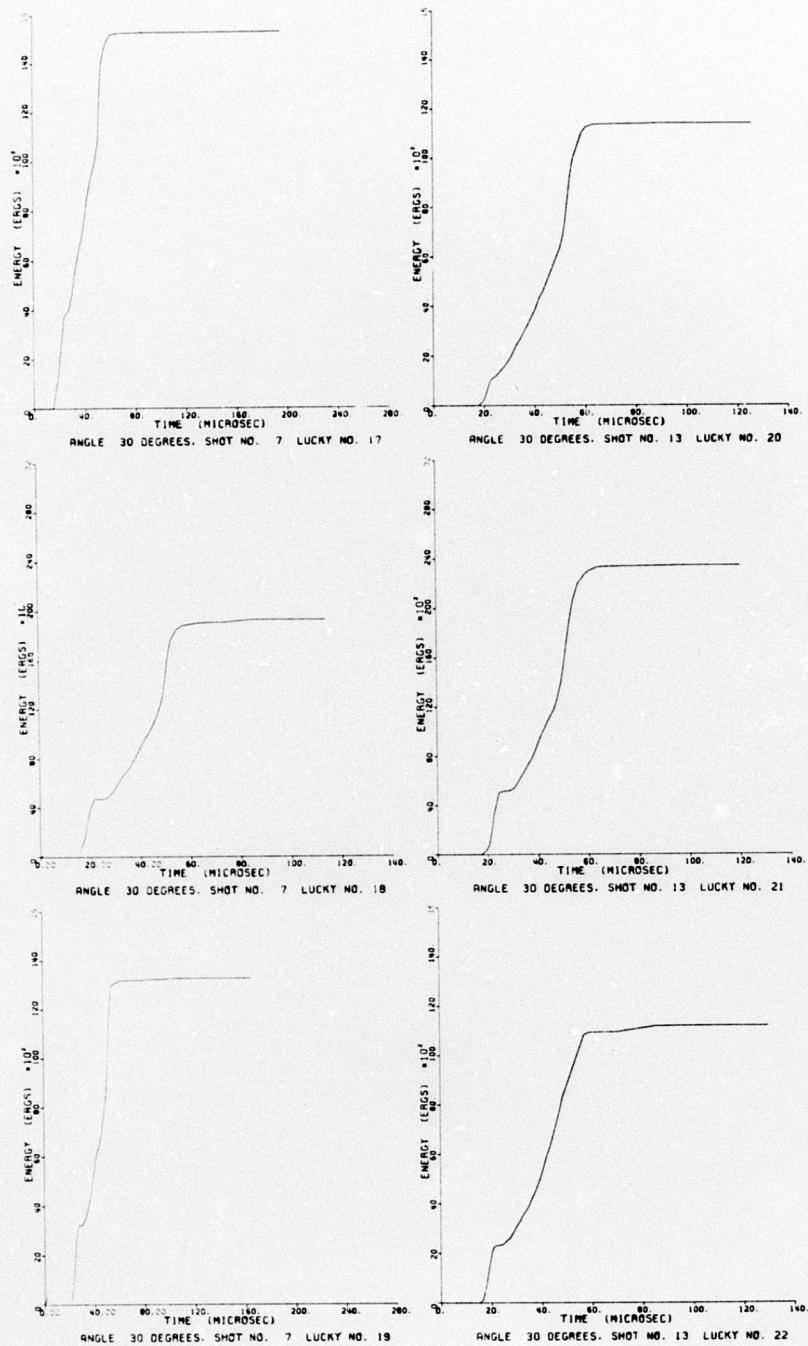
Figure 11d.   Computer plots of Lucky output energy versus time:
Impact angle = 30 deg.

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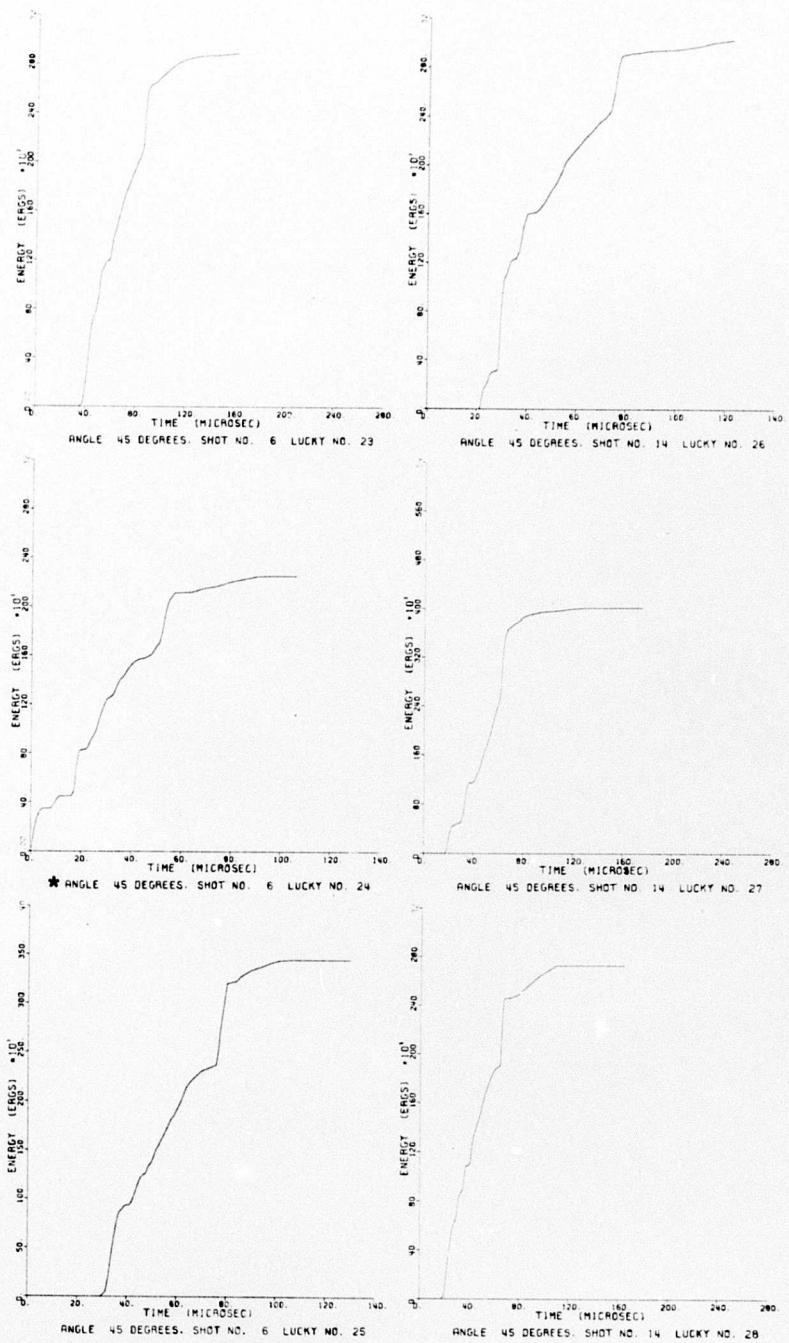
Figure 11e. Computer plots of Lucky output energy versus time:
Impact angle = 45 deg.

*Delay time not obtained; arbitrarily shown as 0.

33
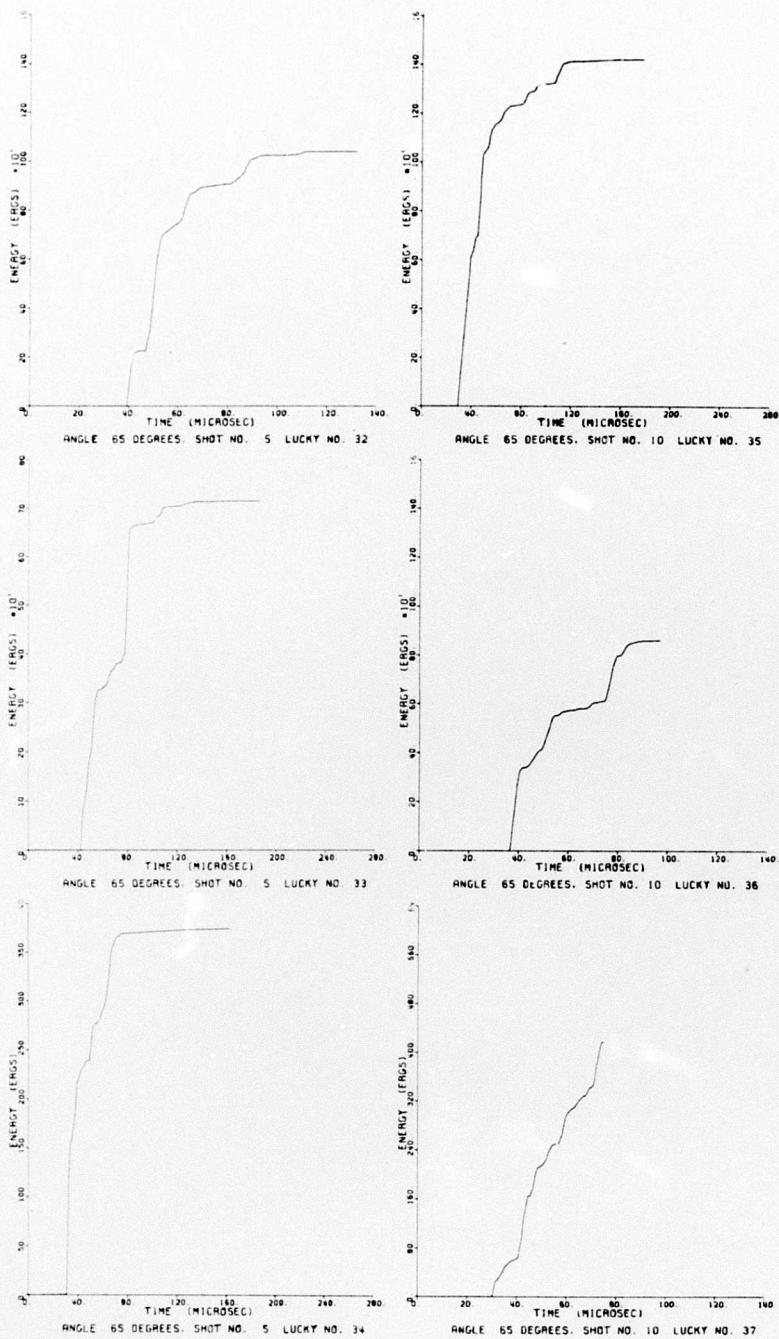
Figure 11f. Computer plots of Lucky output energy versus time:
Impact angle = 65 deg.

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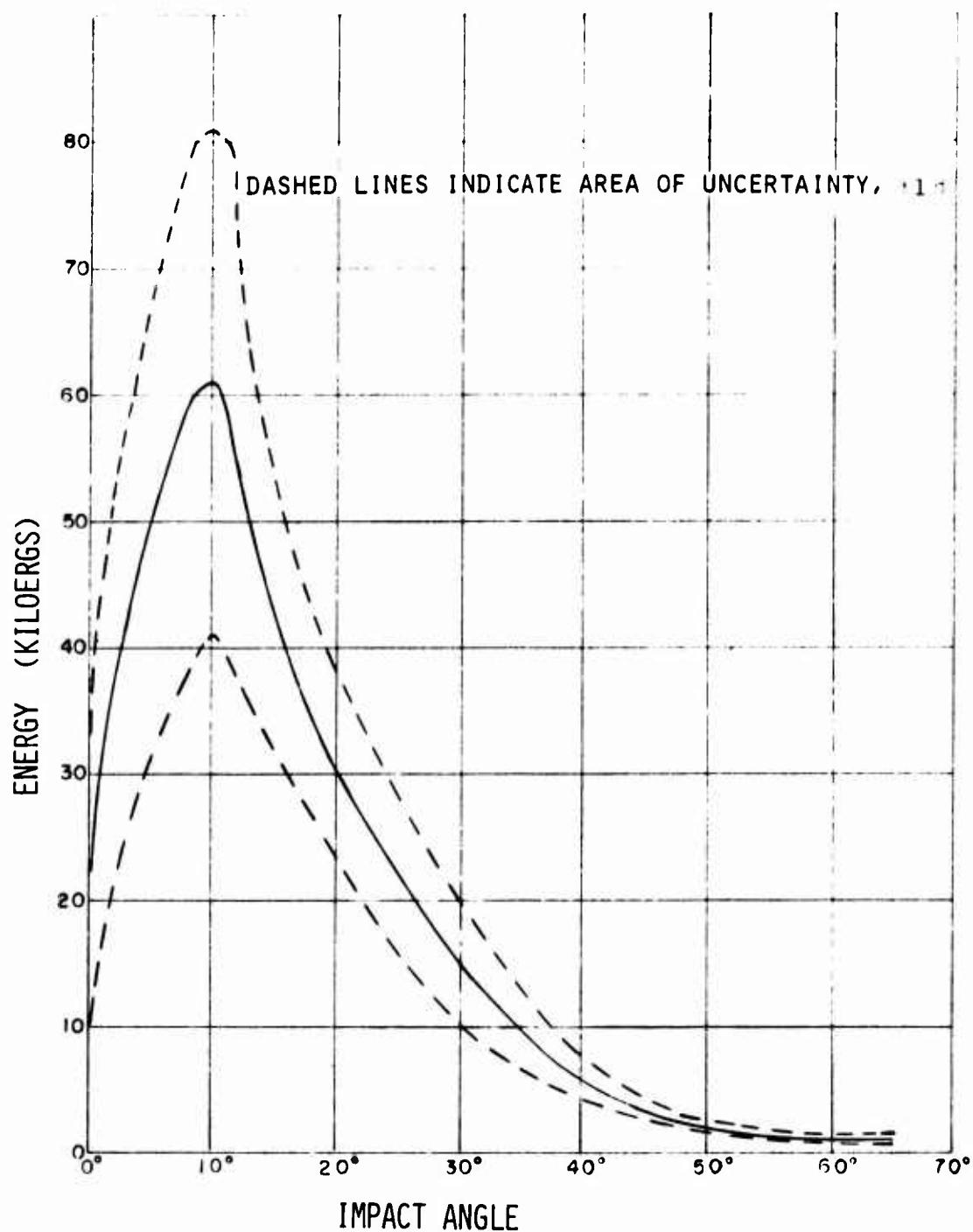
Figure 12. Relation between impact angle and energy dissipated from Lucky elements into a 600-Ω load.